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Zeeman modulated infrared communications system using helium resonance raidation.

Jameson, Henry C. Jr.

Monterey, California: U.S. Naval Postgraduate School

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SYSTEM USING HELIUM RESONANCE RADIATION

HENRY C. JAMESON, JR.

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HELIUM RESONANCE RADIATION

by

Henry C. Jameson, Jr.

Lieutenant, United States Navy

Submitted in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE
IN
ENGINEERING ELECTRONICS

United States Naval Postgraduate School
Monterey, California

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ABSTRACT

The purpose of this paper is to describe an investigation of the feasibility of development of a Zeeman modulated non-image forming infrared voice communication system using helium resonance radiation. During the investigation, experiments were conducted which determined some of the characteristics of the unique detector to be used in the infrared system and other experiments were conducted which determined that the Zeeman modulation of a gaseous discharge light source was feasible.

The theoretical and experimental investigations were performed at the instrument division of Varian Associates in Palo Alto, California, during the period January to March, 1961, while the writer was a student in the Engineering Electronics curriculum at the U. S. Naval Postgraduate School, Monterey, California.

The writer wishes to thank William E. Bell, Dr. Arnold L. Bloom and Nathan Steiger for their assistance and suggestions. The writer gratefully acknowledges the guidance and editoral assistance given him by Professor Carl E. Menneken and Associate Professor Glenn A. Gray.

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I. Introduction

One of the military uses of infrared radiation has been as a
carrier for voice and code communications. Most of the voice com-
munications systems developed are those in which the light source is
intensity modulated at audio frequencies. As such systems might be
in danger of interception by enemy infrared receivers, other types
of modulation which might be more secure have been sought. Several
devices have been developed, one of which makes use of a high frequency
sub-carrier wave and another uses modulated polarization of the light
beam. Another device which has been considered produced modulation
by varying the wave length of the light.

However, all the above systems used wavelengths of light from 0.8
microns to 1.4 microns, a region called the "near infrared" (NIR).[1]
The lead sulfide photoconductor was the first sensitive detector of
radiation beyond 1.4 microns to have a response time short enough to
pick up audio frequency signals. Only with the invention of this photo-
conductor was a system feasible which utilized the "intermediate in-
frared" (IIR) region of the spectrum (1.4 to 6 microns).

All of the detectors used in the systems above, as well as the more
recently developed phototransistors, are relatively broadband in their
spectral response to the incident radiation.

1. The micron is the convenient infrared wavelength unit, and is equal
to 10^{-6} meters or 10,000 Angstroms. Wave numbers are also used;
a wave number is defined as the number of waves per centimeter. Thus,
a 2 micron wave has a wave number of 5,000 cm^{-1}.

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The purpose of this paper is to present a non-image forming IR voice communications system which uses a detector with an extremely narrow spectral response to the incident radiation and in which the audio modulation is accomplished by shifting the wavelength of the transmitted light through the narrow spectral response of the detector by means of the Zeeman effect. The energy in the light beam remains constant and the shift in wavelength is extremely small, so detection of the signal by any means other than by the proposed detector would be very difficult. To avoid confusion, the incident radiation will be referred to by wavelength or wavenumber, while the audio modulation of the light will be referred to by frequency.

Figure 1 is a block diagram of the proposed communications system.

The optical systems and the audio amplifiers are conventional and will not be discussed in this paper. The magnet bias supply is necessary to prevent frequency doubling in the lamp and is similar to the bias supplies used with magnetostriction sonar transducers.

Primarily, the experimental work was directed toward the determination of the characteristics of the unique detector (discharge photocell) to be used in the proposed system and the determination of the feasibility of Zeeman modulation of the light source.

This thesis describes the theory and the experimental work performed at Varian Associates by the writer to demonstrate the feasibility of a Zeeman modulated infrared voice communications system.

BIAS SUPPLY

LAMP EXCITER

AUDIO AMPLIFIER

MICROPHONE

ELECTROMAGNET

LINEAR POLARIZER

HELIUM LAMP

OPTICAL SYSTEMS

TRANSMITTING SYSTEM

PHOTOCELL

LOUDSPEAKER

PHOTOCELL EXCITER

AUDIO AMPLIFIER
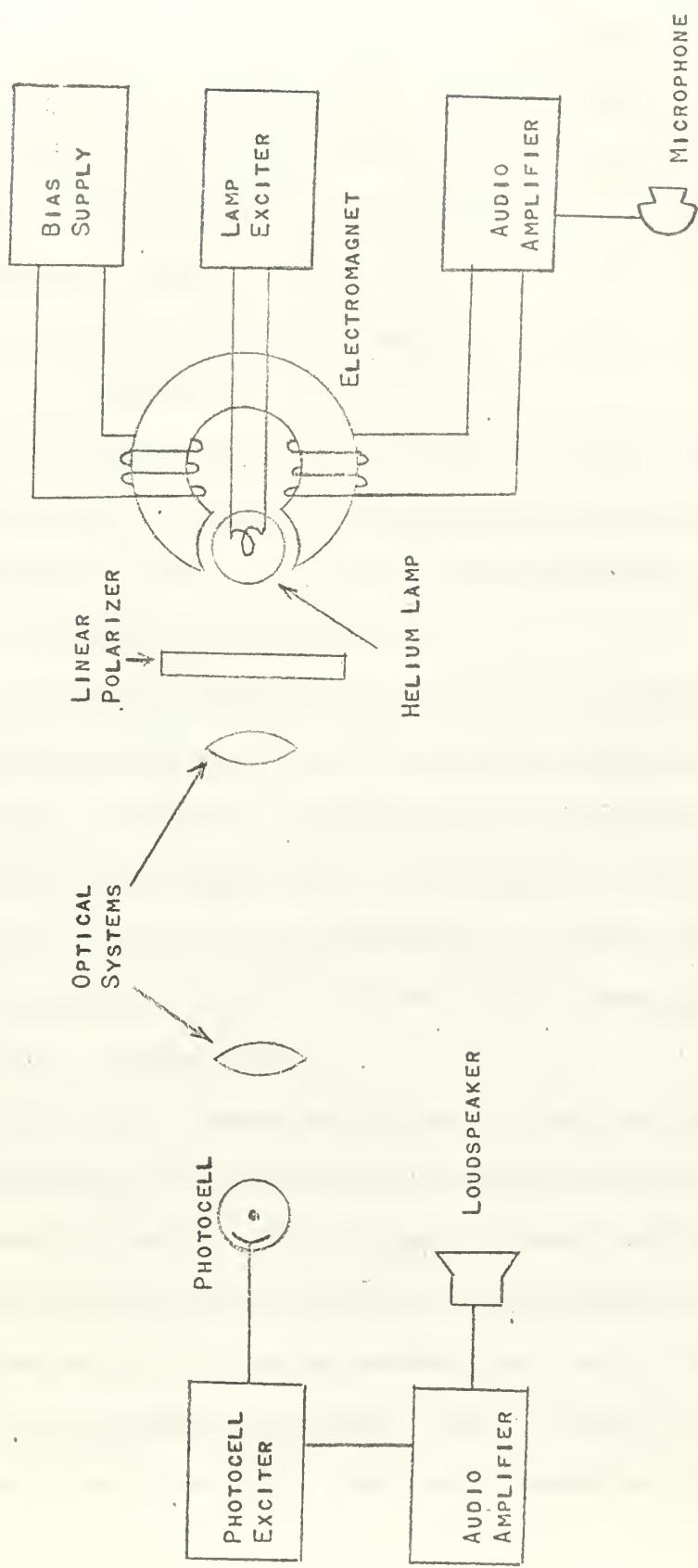
RECEIVING SYSTEM

BLOCK DIAGRAM OF ZEEMAN MODULATED INFRARED COMMUNICATIONS SYSTEM

FIGURE 1

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II. Theory of Operation

The operation of the proposed communications system depends upon a photodetection cell with extremely narrow spectral response to the incident illumination so that minute changes in the wavelength, such as that caused by the Zeeman effect, can be detected. Such a photodetector is the discharge photocell.

    A. Theory of Discharge Photocell

        1. Pure helium

Helium, the second element, is one of the so-called noble gasses, such as neon, argon, etc., and is characterized by having its outer electron shell completely filled. In the case of helium, there is only one shell and it is filled with two electrons.

An atom, when free of external influences, will be found on the average to have its electrons in the lowest energy state. Excited states of an atom, in general, result when one of the electrons is raised to any of the higher energy levels. There are also excited atoms in which two or more electrons are simultaneously in higher levels, but such atoms are observed only rarely in the lighter elements and as a result will not be considered here.

In the ground state (lowest energy state) of helium, the electron spins are antisymmetrical and the vector addition of their spins (called the resultant spin vector "S") is equal to zero. (Helium with antisymmetrical electron spins is called parahelium while helium with symmetrical electron spins is called orthohelium. Only parahelium is of interest in the discharge photocell). With S equal to zero and both electrons in the ground state, the angular momentum of the atom

(denoted by the azimuthal quantum number L) is zero. This state is
called the S state of the atom (not to be confused with the result-
ant spin vector S), while the state with L equal to one is called the
P state. The transition from a 2^1P state to the 2^1S state results in
the emission of an infrared photon with a wavelength of 2.0582 microns,
which is the spectral line of interest in the discharge photocell.
Figure 2 is an abridged energy level diagram for helium showing this
transition.
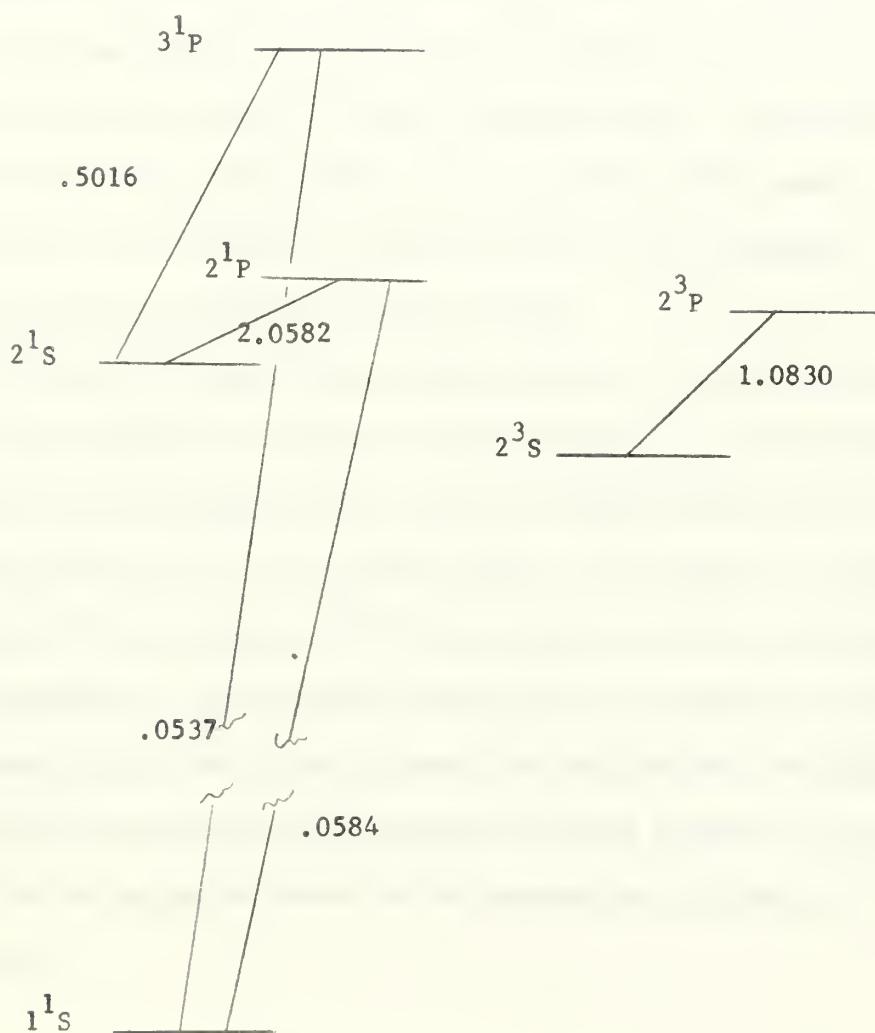
Abridged Energy Level Diagram for Helium

Figure 2

The discharge photocells used in the experiment were bulbs filled with helium under low pressure. In the cell, the helium must be ionized weakly to the extent of having a glow discharge or corona discharge. In the glow discharge, the average energy of the charged particles is insufficient to ionize the helium atoms. However, the average energy of the charged particles is sufficient to excite the atoms to the various 1^P states by direct collision. Most of the excited atoms are returned to the ground state with the emission of a photon of energy, but some fall to the metastable 2^1S state and are trapped, building up a population of metastable excited atoms within the cell. The metastable atom can return to the ground state only by collision with another metastable atom, or by collision with the walls of the container, or by collision with an impurity atom in the gas.

Beutler and Josephy[2] have stated that in a collision of two metastable atoms there is a finite probability that one of the atoms will capture all the energy and be raised to a higher state while the remaining atom returns to the ground state. In helium, the metastable capturing all the energy will become ionized as the combined energy of two metastables is greater than the ionization potential of helium. The probability of collision between two metastables, and thereby the equilibrium concentration of charged particles present in the gas, is a function strongly dependent on the metastable population in the glow discharge.

2. H. Beutler and B. Josephy, Phil Mag 5, 222 (1928).

The conductance of the gas in the corona discharge is a direct function of the concentration of charged particles in the gas. Any phenomenon which can change the metastable population can be detected as a change in the conductance of the gas. Penning[3], while studying the starting potentials in neon, discovered that when a glow discharge, depending on the maintenance of a population of metastables, is illuminated with the resonance radiation from a strong discharge of the same gas, the metastable population is diminished and the characteristics of the discharge altered. This is accomplished by the resonance radiation exciting the metastable atoms to a higher non-metastable state from which the radiative transition to the ground state is not forbidden and the branching ratio is favorable for a return to the ground state.

In parahelium, the metastable state is the 2^1S. The transition from this state to the ground state is forbidden by the quantum mechanical selection rule $\Delta L = \pm 1$. A photon of resonant radiation of 2.0582 microns can raise an electron from the 2^1S state to the 2^1P state from which the transition to the ground state is highly allowed and the branching ratio is 1780:1.97.[4] This means that for every 2000 metastables raised to the 2^1P state all but approximately 2 will fall to the ground state with the emission of a photon with a wavelength of .0584 microns. As the energy levels are quite sharp, the spectral bandwidth of the resonant radiation exciting the metastables is quite

3. F. M. Penning, Phil Mag 11. 961 (1931)
4. A. H. Gabriel and D. W. O. Heddle, Proc Royal Soc 258, 123 (1960).

narrow, probably on the order of the width of the spectral emission line from the corona discharge. It has been estimated by Bell and Bloom[5] that the bandwidth for the detection of the 2.0582 micron line is about 0.1 cm^{-1}.

5. W. E. Bell and A. L. Bloom, "Discharge Photocells for the Detection of Resonance Radiation", unpublished pamphlet, Varian Associates, Palo Alto, California.

2.   Effects of buffer gasses

As was stated previously, the metastable helium atoms can lose
their excess energy by collision with another metastable, or by col-
lision with the walls of the container, or by collision with an im-
purity atom in the gas. Collisions between metastables is the mechan-
ism which produces the charged particles in the cell. Collision of
metastables with the walls of the container can be controlled by keep-
ing the dimensions of the container large relative to the mean free
path of the atoms in the gas. Collisions of metastables with impurity
atoms can be controlled by controlling the partial pressure of the im-
purity gas in the cell.

The addition of impurity atoms to the helium diminishes the ef-
fective equilibrium concentration of metastables in the corona dis-
charge and lowers the sensitivity of the cell to the resonance radia-
tion. However, the sensitivity of the discharge photocell to the lower
modulation frequencies is diminished much more than is its sensitivity
to the higher modulation frequencies. This selective lowering of the
sensitivity by the added impurities results in an audio frequency response
curve with a wider bandwidth than that of pure helium.

The process of building up the metastable population by electron
bombardment requires a finite amount of time. Should the population
be reduced by illumination with resonant radiation, and the illumina-
tion be abruptly terminated, the amount of time required for the build
up to the equilibrium concentration is a function of the population of
metastables in the equilibrium condition. The larger population requires
a greater amount of time to build up than does a smaller one. With pure

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helium, the equilibrium concentration of metastables is so large that a relatively long period of time is required to reach the equilibrium condition. Then, when the modulation frequencies are increased above a few hundred cycles per second, insufficient time is allowed during the cycle for the population of metastables to reach equilibrium, and therefore the sensitivity of the cell is decreased for these higher frequencies. With impurity atoms added, the equilibrium population of metastables is lowered, the time required for the electron bombardment to return the metastable population to equilibrium is shortened; and, therefore, higher modulation frequencies can be reached before the time allowed for the build up during the modulation period becomes a limiting factor.

The energy of an atom is partially determined by its angular momentum. The total angular momentum (denoted by the quantum number J) is the sum of the vectors L and S. However, in parahelium, S is always equal to zero; therefore, J is equal to L. When a magnetic field is impressed on the infrared light source, the orientation of the total angular momentum relative to the magnetic field determines additional energy levels. The additional energy terms separate a given level into discrete sublevels according to the discrete orientation of the total angular momentum relative to the magnetic field. The rigorous quantum mechanical magnitude of the total angular momentum vector is $\sqrt{J(J+1)}$ $h/2\pi$. This vector has no fixed direction in space, but does have discrete values of projected components along the reference direction, in this case, the magnetic field. This means that J is "space quantized" in a magnetic field. These projected components for the 2^1P state are $Jh/2\pi$, 0, and $-Jh/2\pi$, and are denoted by another number M such that M is equal to J, 0, and -J, for a total of $2J + 1$ values.
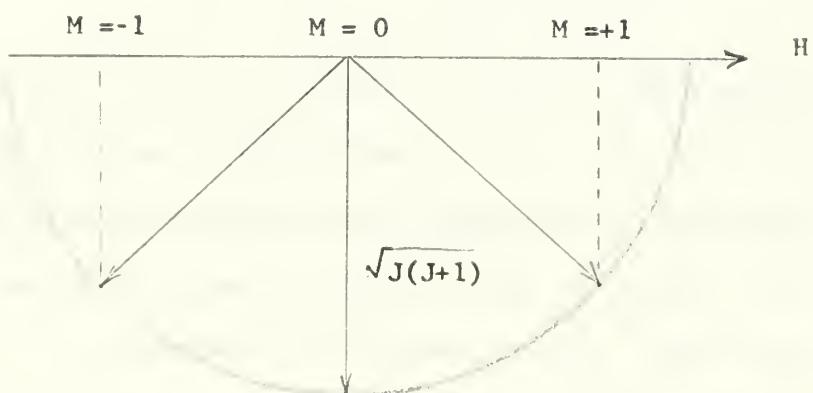
Space Quantization for J = 1

Figure 3

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The energy in a magnetic field is:

$$W = W_c - H\mu_H$$

where W_o is the energy of the field free case

H is the strength of the magnetic field

μ_H is the component of the magnetic moment in the direction of the field.

From classical mechanics, the magnetic moment resulting from the revolution of a negative electric point charge is:

$$\mu = -\frac{e}{2mc}\,p$$

where p is the angular momentum and m is the mass of the charged particle. Then,

$$\mu_H = -\frac{e}{2mc}\frac{h}{2\pi}M$$

is the component of μ in the H direction.

The energy is then

$$W = W_o + \frac{e}{2mc}\frac{h}{2\pi}MH$$

As M must be 1, 0, or -1 for the ^1P state, the separation of the sublevels must be directly proportional to H. For M = 0, the energy in the field is the same as the energy out of the magnetic field, and the wavelength of a photon emitted in the transition $2\,^1P \longrightarrow 2\,^1S$ with $\triangle M = 0$ is unchanged by the magnetic field. (Note that M = 0 is the only value for M when the atom is in the S state). With $\triangle M = \pm 1$, the change in magnetic energy in wave numbers is:

$$\pm(4.67 \times 10^{-5})H$$

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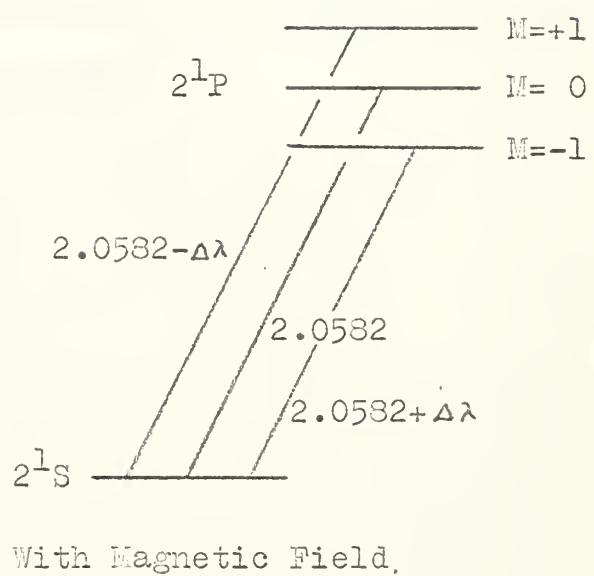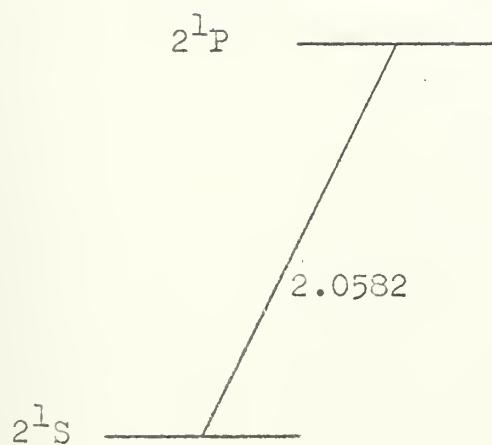
Zeeman Splitting of 2^1P Levels

Figure 4

The wave number for the 2.0582 micron line is 4858 cm^{-1}.

The line with $\triangle$ M = 0 (π line) is polarized parallel to the magnetic field while the lines for $\triangle$ M = ± 1 (σ lines) are polarized perpendicular to the magnetic field.

As the acceptance bandwidth for the 4858 cm^{-1} line (2.0582 microns) is only 0.1 cm^{-1}, it can be observed from the foregoing equation that only magnetic field strengths on the order of 1 or 2 kilogauss are necessary to shift the spectral lines this amount.

III. Procedures and Results of Experiments

The information to be obtained from the experimental work was primarily on the feasibility of a communication system using Zeeman modulated resonance radiation and a discharge photocell as a detector. In order to construct a workable system it was necessary to find the answer to several questions about the discharge photocell before attempting to modulate the light source by means of the Zeeman effect. Most of the experimental effort went into attempts to obtain answers to these questions. Some of the principal questions were:

      (a) What is the signal output of the cell as a function of:

            (1) Modulation frequencies?

            (2) Electrode potentials?

            (3) Helium pressure?

        (b) What is the signal to noise ratio in a useable system?

        (c) How can the detector best be matched to the indicator?

   (d) What is the optical thickness of the cell for the 2 micron line of resonance radiation?

Experiments were designed and conducted in an attempt to provide answers to some of these questions.

. Preliminary Experiments

1. The first experiment to be conducted was designed to determine a good method of coupling the detector to the indicator. Two methods of coupling were examined; one in which an electrodeless discharge photocell was closely coupled to the coil of an oscillator (detector-oscillator) and one in which the discharge photocell electrodes were directly coupled to a resistor-capacitor network.

The detector-oscillator was an RF oscillator with the discharge photocell closely coupled to the tank coil. (Figure 5 is a schematic of the detector-oscillator used in the experiment). The oscillator supplied sufficient RF energy to the discharge photocell to excite the gas. A change in the conductance of the cell was reflected as a change in the loading of the oscillator and, thereby, a change in the equivalent impedance of the oscillator circuit. With a constant current supply used to power the device, variations in the equivalent impedance of the circuit caused variations in the voltage across the oscillator which were amplified by the preamplifier and monitored by the oscilloscope to indicate the signal.

The second method of coupling the detector to the indicator was by means of a resistor-capacitor network. The gas in the discharge photocell was excited by the application of DC potentials to internal electrodes. (See Figure 6). The collector electrode was connected to the power supply through a resistor. Changes in the ion current through the cell caused voltage variations across the collector resistor. These voltage variations were coupled through a capacitor to the preamplifier, where they were amplified. The output of the preamplifier was monitored by an

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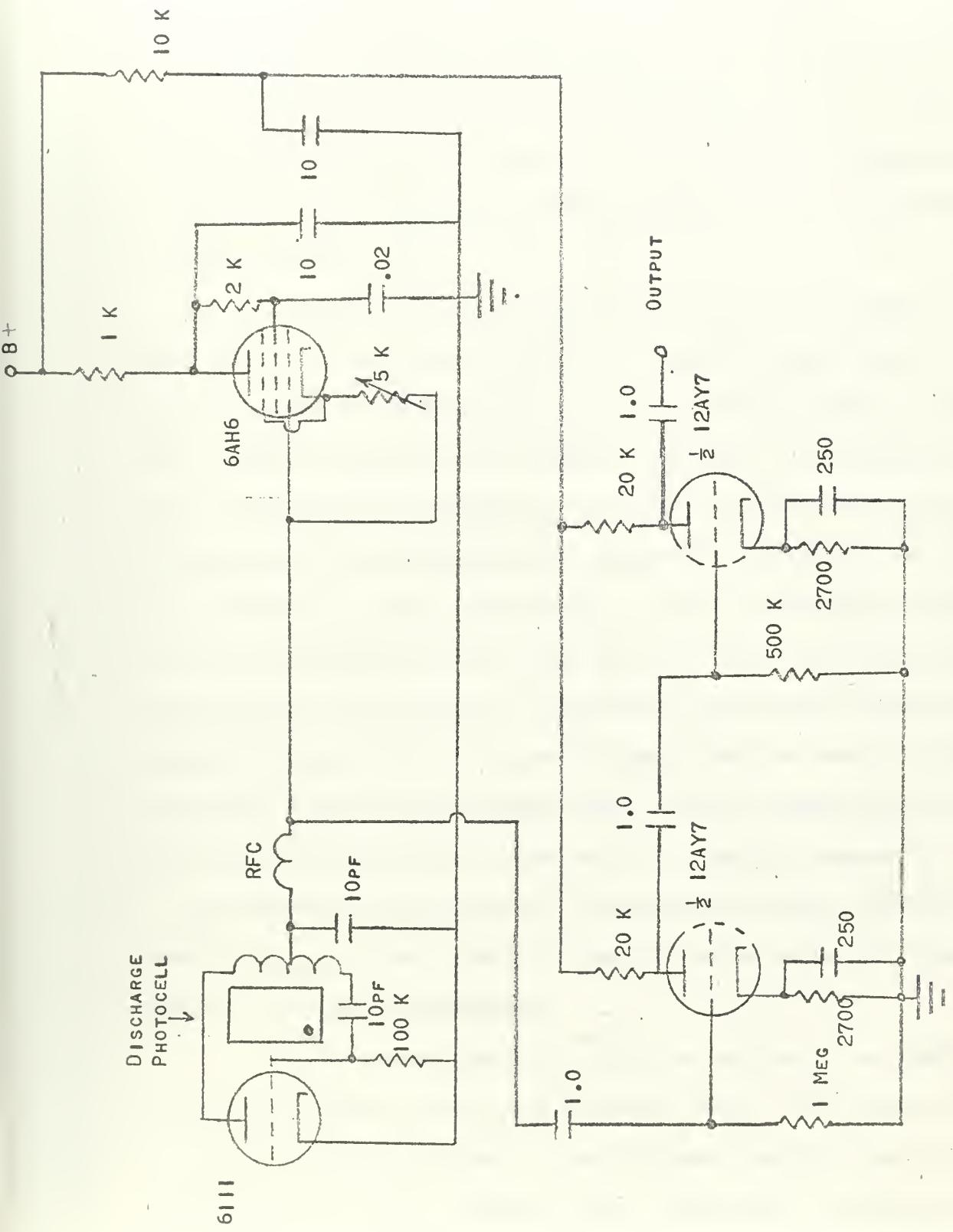
Schematic of Detector-Oscillator

Figure 5

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oscilloscope to indicate the signal.

Due to large amounts of noise in the resistor-capacitor coupled photocell, the detector-oscillator appeared to be a better method of coupling the discharge photocell to the indicator; however, in most of the following experiments the resistor-capacitor method of coupling was used because the pressure and electrode potentials could be controlled in that particular cell.

2.   The detector oscillator was used in an experiment to determine if the cell was optically thick. A spherical mirror was placed directly behind the discharge photocell and located so that only light first passing through the cell would be reflected. With the mirror in place, the signal was increased by a factor of approximately two over the signal with the mirror removed, indication that the cell was not optically thick. A very thin coating of silver was deposited chemically on the cylindrical walls and one end of the cell to provide a reflective surface to the infrared. Unfortunately, the silver loaded the oscillator so greatly that no corona discharge could be created in the photocell. Efforts to etch rings around the cell through the silver to reduce the shunting effects failed and the silver was removed.

The pressure in this photocell could not be changed; therefore, the effects, if any, of the pressure of the gas on the optical thickness of the cell could not be determined.

3.   The noise level of the detector-oscillator was considerably lower than the noise level of the photocell used in the pressure and electrode potential experiments. The discharge photocell used for this experiment was a GIC-011 ionization tube. There was no troublesome

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microphonic or low frequency noise in the oscillator circuit, but the microphonic and low frequency noise was extremely high in the ionization tube circuit.

4. The discharge photocell was exposed, in turn, to high intensity chopped light from a tungsten lamp and a mercury vapor lamp. No detectable signal was observed from either of these sources. Thus, the discharge photocell demonstrated an excellent rejection of extraneous light.

E. Optimization of Gas Pressure and Electrode Potentials

The study of the effects of helium pressure and electrode potentials was undertaken next. In these experiments, the modulation frequency of the light remained constant, while the pressure in the cell and the electrode potentials were varied. The discharge photocell was connected to a vacuum system so that the pressure of the helium in the cell was controllable. The gas in the photocell was excited by controllable DC voltages applied to internal electrodes. This study of the pressure effects tended to divide itself into two distinct experiments. For pressures below 1 micron[1], a vacuum ion gauge was available to indicate the pressure. For pressure above 1 micron, it was planned to use a thermocouple gauge; however, as this gauge proved unsatisfactory, a McLeod gauge was installed later to indicate these pressures.

1. Pressure below 1 micron

Figure 6 is a block diagram of the pressure and electrode potential experiment. The lamp was an electrodeless discharge excited by an RF oscillator coupled to external electrodes at the ends of the bulb. The lamps had been degassed at high temperature in order to eliminate impurities arising from the glass walls prior to the introduction of the spectroscopically pure helium.

No attempt was made to place a reflector behind the lamp; however, a plastic fresnel lens with a relative aperture of approximately f/1.5 was placed in front of the lamp and the infrared radiation focused on the slot of the light chopper.

The light chopper consisted of a stationary mask with a

1. In pressure measurements, 1 micron is equal to 10^{-3} mm Hg.

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slot cut in it and a revolving disk driven by a series AC motor. The disk was about 8 inches in diameter and had 78 slots milled around a circle near the edge. The slots in the disk were approximately the same size as the one in the mask, and were separated by about a slot width. The speed of the motor was controlled by a Variac in the power line and the device was capable of modulation frequencies in excess of 5000 cps.

The discharge photocell used for this experiment was connected to the vacuum system by means of a pyrex tube. The grid voltage was continuously controllable from 0 volts to +600 volts and the collector voltage was controllable from 0 volts to -180 volts. The filament voltage was variable from 0 to +12 volts.

A two stage low noise audio preamplifier was constructed using a low noise 12AY7 twin triode, and was connected to the collector of the photocell. **3 db** bandwidth of the pre-amplifier was measured as from 8 cps to 160 kcps. The equivalent noise voltage of the amplifier was determined to be 20 micro-volts.

A frequency of 100 cps was selected as the constant frequency for this experiment. In order to reduce the effects of noise in the system, a bandpass filter with center frequency of 100 cps was installed between the amplifier and the oscilloscope. This filter was a Krohn-Hite model 330-A ultra-low frequency bandpass filter.

The GIC-011 vacuum gauge tube was extremely microphonic and it exhibited a mechanical resonance around 100 cps. In addition to the microphonic noise and the gas noise present, a large amount of low frequency noise was observed.

The experiment was conducted by filling the photocell to a pressure of a few hundred microns of helium and adjusting the circuit voltages until the modulation signal of the light was observed on the oscilloscope. With the circuit voltages thus optimized, the discharge photocell was pumped down slowly, while attempting to keep the signal observable on the oscilloscope.

Each time the pressure was lowered in the cell, the signal was lost in the noise before a pressure of 1 micron was reached. Therefore, no data was obtained concerning the operation of a discharge photocell at pressures below 1 micron.

2. Pressures above 1 micron

As the experimental work with pressures below 1 micron met with no success, the next experiment performed was the optimization of pressures above 1 micron.

The thermocouple gauge was to be used as the pressure indicator, but it was not calibrated for helium. The specific heat of helium caused great variances in the pressure readings from the readings with air, for which the gauge was calibrated. It was decided to conduct the experiment and then calibrate the thermocouple gauge for helium on another vacuum system equipped with a McLoed gauge.

The mechanical chopper was discovered to be a source of vibration which contributed to the microphonics in the discharge photocell. It was also discovered that the apertures of the slots were too small. The lens and slots tended to concentrate the light in a very narrow ribbon passing through the gaseous discharge and as a result, the illumination was highly inefficient.

An electronic means of modulation of the light was adopted. A 220 volt to 5 volt filament transformer was placed in the line between the power supply and the lamp exciter. A nominal 40 watt audio amplifier, driven by an audio oscillator, was coupled to the 5 volt winding. The plate and screen voltage of the lamp exciter oscillator could be modulated up to 100% in this manner for fairly low frequencies. The mechanical chopper was removed.

The removal of the mechanical chopper, slot and the fresnel lens together with moving the lamp slightly closer to the discharge photocell increased the signal output by two orders of magnitude, and

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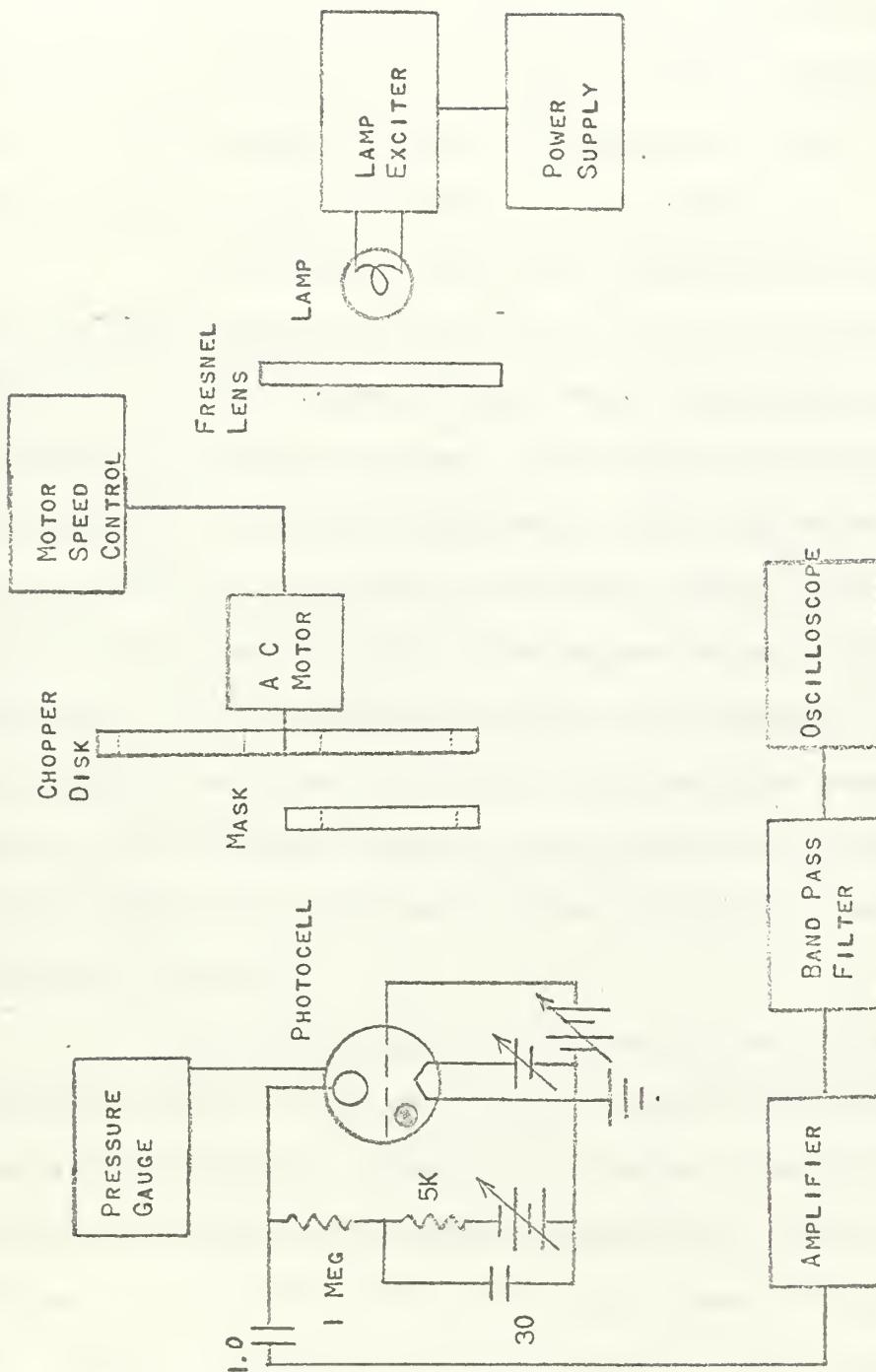
BLOCK DIAGRAM OF PRESSURE AND ELECTRODE POTENTIAL EXPERIMENT

FIGURE 6

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reduced the microphonic noise in the tube. (As this gain in signal output was significant, another attempt was made to obtain date at pressures below 1 micron, but this, too, was unsuccessful).

During the test, it was discovered that for conditions which gave large signal output the signal increased slightly when the filament voltage decreased to zero. The electric fields in the photocell were strong enough to maintain the glow discharge.

Several sets of data were taken using the thermocouple as the pressure measuring device, but they were not too meaningful. (Figure 7 is a block diagram of this system). The thermocouple failed to indicate the pressure accurately. The range of readings on the thermocouple was from 1 micron to 1 atmosphere. This range seemed excessive and, when the thermocouple gauge was checked against a mercury manometer, it proved to be grossly in error. The maximum pressured used was about 4000 microns. It was impossible to repeat the readings on the thermocouple gauge to any degree of accuracy. (It was later possible to obtain data for a plot of signal response versus pressure using another type of vacuum gauge and the electronic method of modulating the light. This is discussed in Part C).

Using what appeared to be near optimum pressure and a modulation frequency of 300 cps, data for curves of the signal response versus grid and collector voltages were obtained. (See Figures 8 and 9). The response was found to be fairly independent of collector voltage, changing by only 25 percent for a 100 percent change in collector voltage. However, the response was very dependent on grid voltage, changing 100 percent for a 40 percent change in grid voltage.

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Block Diagram of Amplitude Modulated System

Figure 7

f = 300 cps   P = 1000 microns
V_{grid} = +580 volts
V_{fil} =   0 volts

-100
-200
-300

Collector Voltage

Relative Signal Output Vs Collector Voltage

Figure 8

f = 300 cps
P = 1000 microns
V_{coll} = -150 volts
V_{fil} =   0 volts

200   Grid Voltage   400
600

Relative Signal Amplitude Vs Grid Voltage

Figure 9

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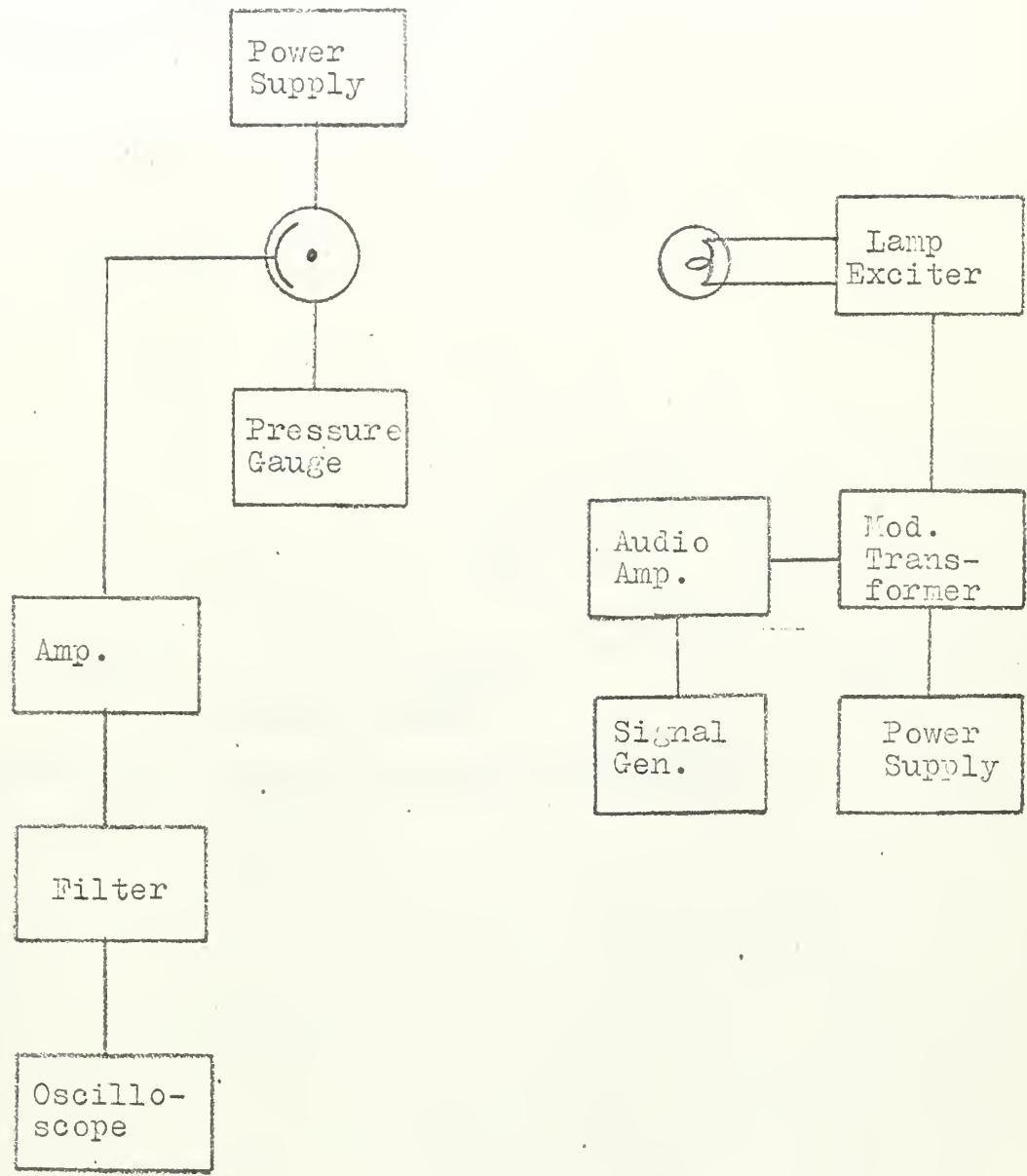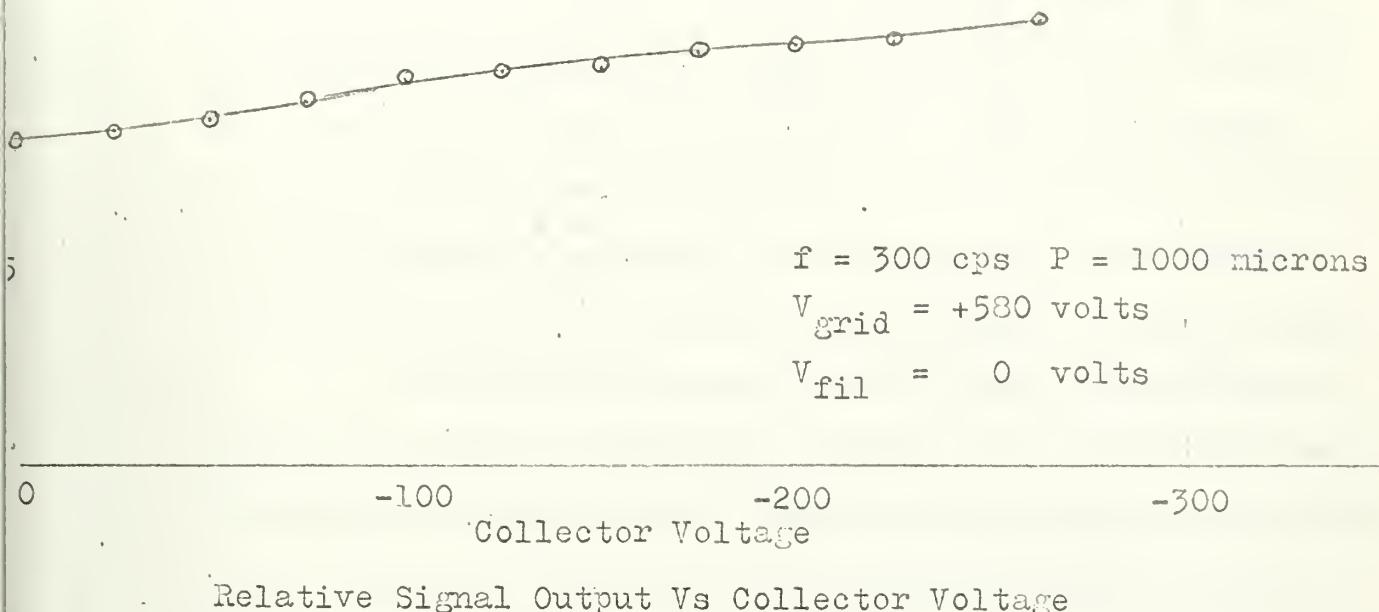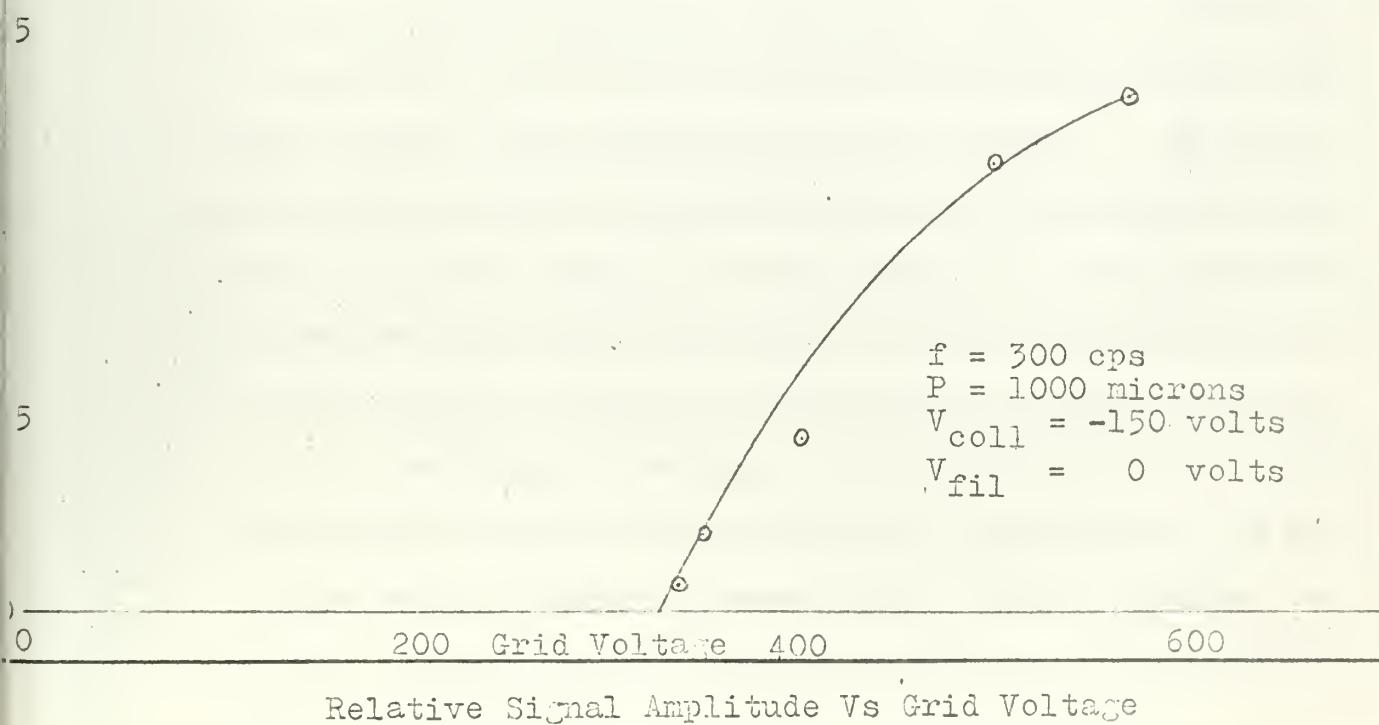
E. Frequency Response of the Discharge Photocell

After several sets of data for pressures above 1 micron had been taken, it was discovered that the thermocouple gauge was so unreliable as to nullify the data taken. Through the use of a mercury manometer it was discovered that the range of pressures of interest was from 1 micron to about 4000 microns. It was necessary to provide an accurate pressure indication and a McLoed gauge with that range was obtained and connected to the vacuum system through a liquid air trap.

As the electronic modulation of the light had been successful, it was decided to reverse the procedure of the experiment and vary the modulation frequency of the light while maintaining a constant pressure in the cell. This procedure was repeated for several pressures within the range of interest.

While the filament transformer performed very well for the constant low frequency in the previous experiment, its characteristics were not suitable for use over a wide range of modulation frequencies. Consequently, it was decided to obtain an audio transformer whose frequency response characteristics would be more suitable. A UTC LS-58 audio output transformer was installed in place of the filament transformer in the plate supply of the lamp exciter. It was not possible to modulate the plate supply of the exciter 100% with this transformer but the audio frequency response of this transformer was greatly superior to that of the filament transformer. A calibration curve for the modulation system was obtained with the use of a phototransistor, and the curve was used to correct the photocell data. Figure 10 presents the corrected frequency response curves of the photocell for selected pressures.

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The conditions on the lamp were held as nearly constant as possible during the entire set of runs so that comparison between runs could be made. The percent modulation of the light was determined by a Hoffman solar cell to be 40 at a frequency of 100 cps.

It was noted during the runs that some of the data produced rather flat frequency response curves. (See Figure 11). Investigation showed that during these runs the characteristic glow of the discharge photocell had changed color, an indication that impurities had somehow become mixed with the helium. These impurities were assumed to be air molecules which had leaked through the connections of the McLoed gauge.

In order to assist in the determination of an optimum pressure, for the discharge photocell and to cross-check the frequency response data obtained, a test was conducted in the manner of the previous experiment. A constant modulation frequency of 10,000 cps was selected and the pressure in the cell was varied from about 800 microns to 1600 microns. The result of this test is presented in Figure 12.

From Figures 10, 11 and 12, it can be concluded that a pressure in the range of 1100 to 1200 microns would be an optimum pressure for the gas in the photocell. From Figure 11 it can be noted that the addition of impurities in the gas greatly reduced the overall sensitivity of the cell to the incident radiation.

FIGURE 10

FREQUENCY RESPONSE FOR SELECTED PRESSURES

GIC-011

0-DB IS MAXIMUM RESPONSE AT 100 CPS

V_{GRID} = 520 VOLTS

V_{COLL} = -87 VOLTS

V_{FIL} = 0 VOLTS

1200 μ

950 μ

2000 μ

FREQUENCY

30
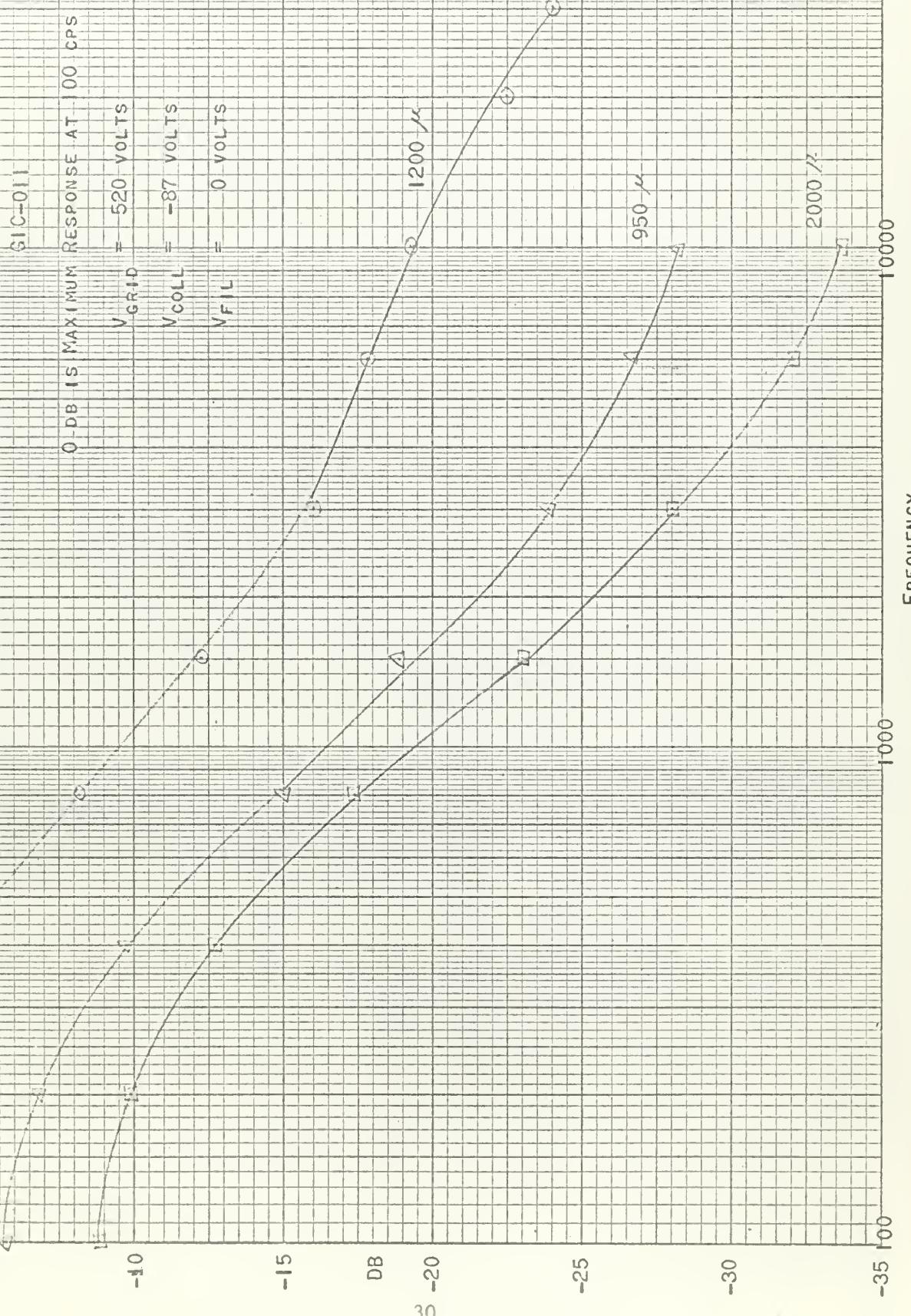
FIGURE II

FREQUENCY RESPONSE FOR SELECTED PRESSURES
(WITH IMPURITY GAS)

GIC-011

0 DB IS MAXIMUM RESPONSE OF PURE HELIUM AT 100 CPS
(SEE FIGURE 10)

V_{GRID} = 520 VOLTS

V_{COLL} = -87 VOLTS

V_{FIL} = 0 VOLTS

1200 μ

1900 μ

FREQUENCY

$V_{grid} = +500$ volts

$V_{coll} = -36$ volts

$V_{fil} = 0$ volts
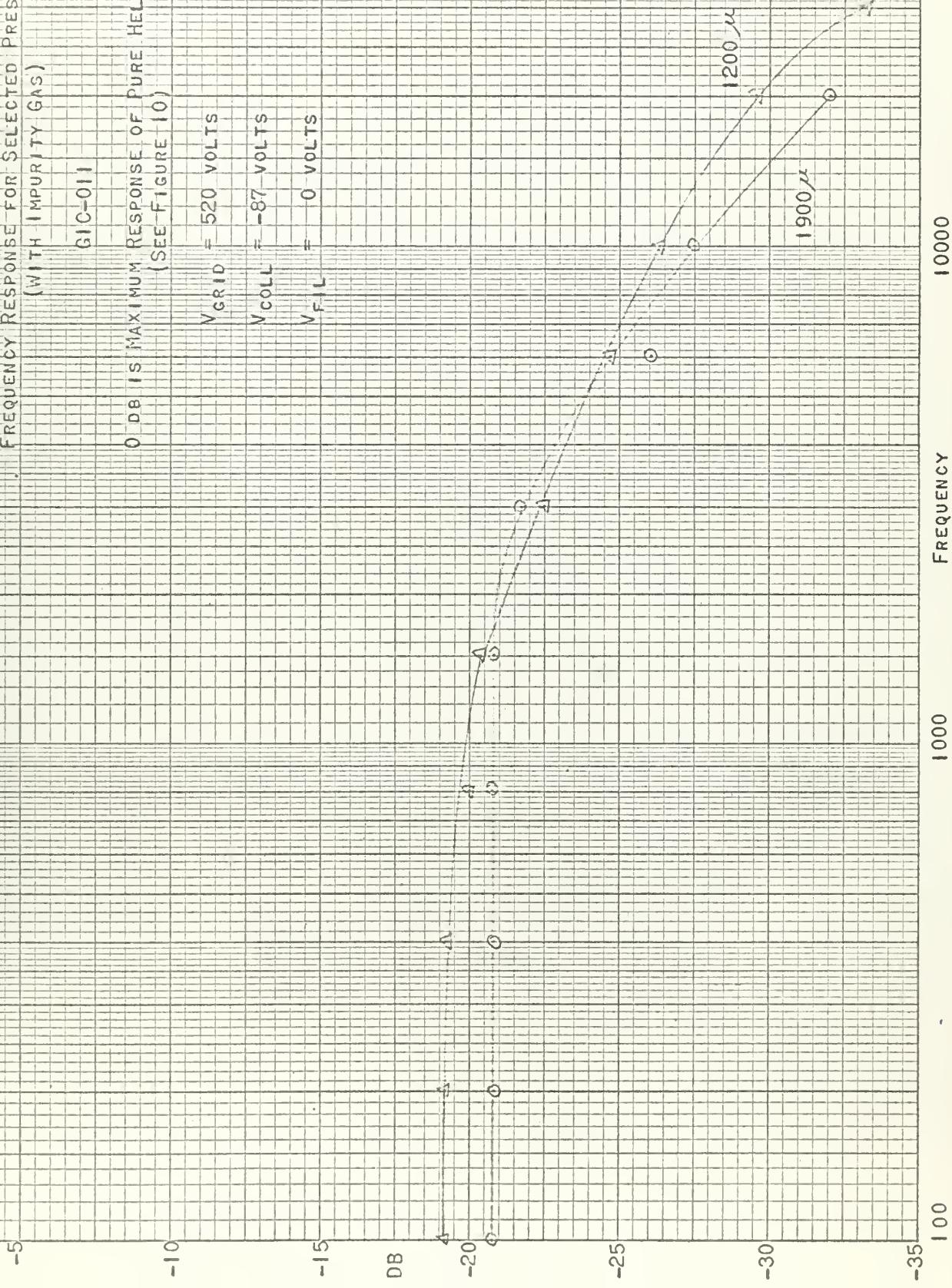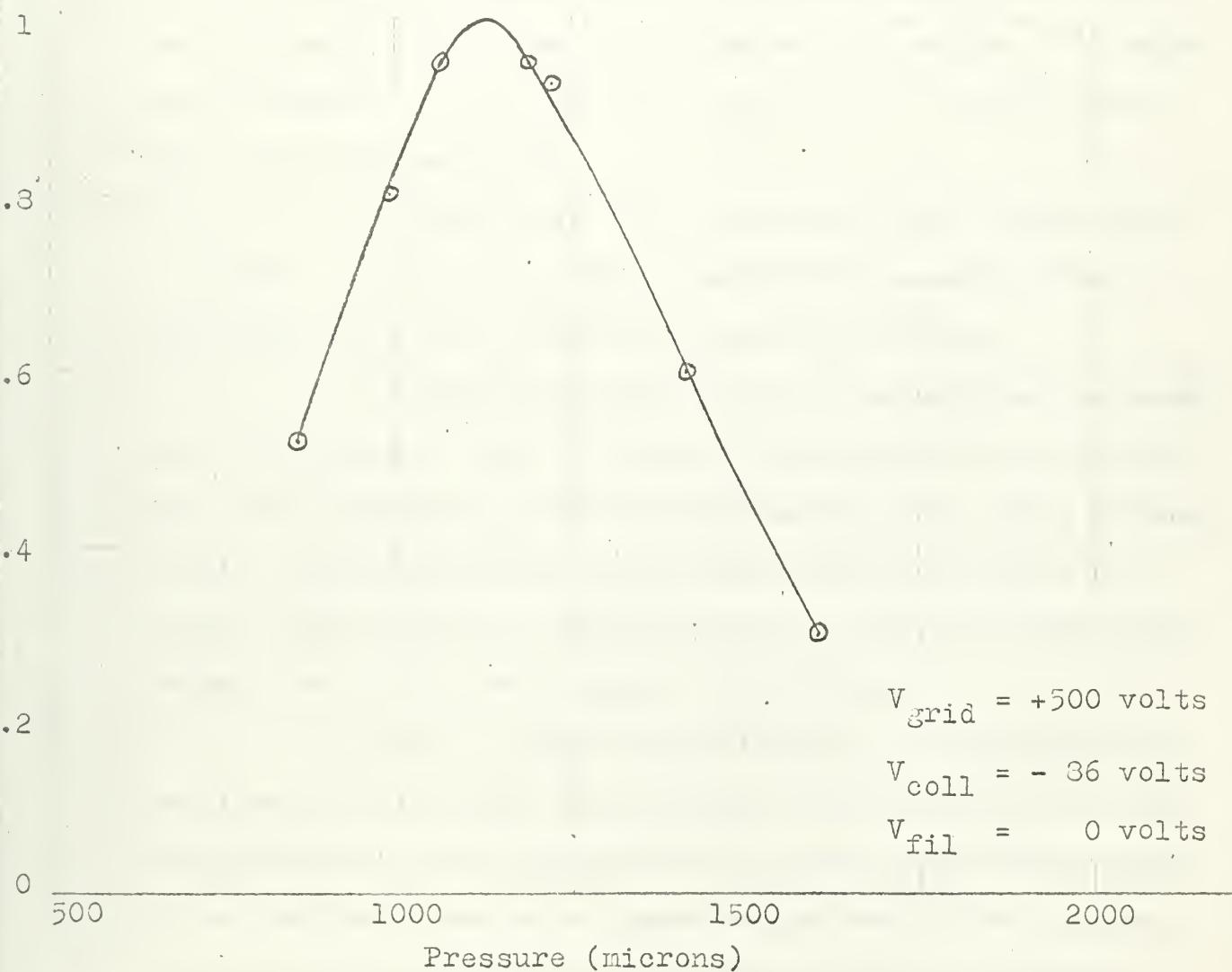
10 Kilocycle Response Vs Pressure

Figure 12

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D. Zeeman Modulation

A magnet was constructed with a field coil of 650 turns of #12 aluminum wire. This coil was placed on a grain oriented, laminated silicone steel core of about one centimeter square in cross-section. A gap of one centimeter was cut from the core and the lamp capillary placed between the pole faces. A field strength of about .80 Kilogauss per ampere coil current could be impressed on the lamp. The magnet had an inductance of 107 millihenries and a Q of 11.7. The DC resistance of the coil was 1.5 ohms.

An opaque plate with a slot cut in it was mounted directly in front of the lamp to reduce the unmodulated resonance radiation from those portions of the lamp not between the pole faces.

A Polaroid Corporation Type HR linear polarizer was placed in front of the slot. The HR filter was oriented so that it would block light which was polarized parallel to the magnetic lines of flux (π lines) and pass that light polarized perpendicular to the lines of flux (σ lines). This filtering is necessary because π lines do not shift wavelength as the lines do when a magnetic field is applied.

Data for a graph showing the effects of signal amplitude versus magnet field strength were obtained. (See Figure 13.) The modulating frequency of the light was 500 cps. It was noted that the signal did not decrease to zero as the current through the coil was increased. There are at least two causes of this effect. First, the capillary of the lamp was not in a uniform magnetic field. This non-uniformity was caused by fringing effects resulting from the width of the air gap being on the order of the cross-sectional dimensions of the magnet core.

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Second, the π lines were not completely attenuated by the linear
polarizer.

From Figure 13 it can be observed that the response of
the photocell is fairly linear with magnetic field strengths imposed
on the lamp for magnetic fields up to about one kilogauss. With the
design of a more efficient magnet, the steepness of the curve could be
increased, thereby requiring a lesser magnetic field current to modu-
late the lamp.

The transformer was removed from the plate and screen
supply of the exciter and the audio power amplifier was connected to
the field coil of the magnet. Figure 14 is a block diagram of this
system. The power amplifier was incapable of supplying sufficient cur-
rent to the magnet coil to permit a satisfactory degree of Zeeman modula-
tion of the lamp. However, a small signal was observed, with a signal
to noise ratio of 1.8 to one. The magnetic pickup was extremely high due
to the proximity of the magnet coil to the detector; this magnetic pick-
up accounted for about 90 percent of the noise present. Observation of
the signal was facilitated by the fact that with no bias current through
the magnet, the signal out is at twice the frequency of the input signal.

In order to increase the current through the coil, a fre-
quency of 120 cps was selected, the power amplifier removed from the
circuit and a Variac connected to the field coil. The distance between
the lamp and the detector was increased by ten inches. The magnetic
pickup was considerably reduced from the previous condition even though
the current in the coil was increased. The Krohn-Hite filter was used to
remove the fundemental frequency component of the magnetic pickup.
A signal to noise ratio of three to one was observed, with most of the
noise again resulting from magnetic pickup.

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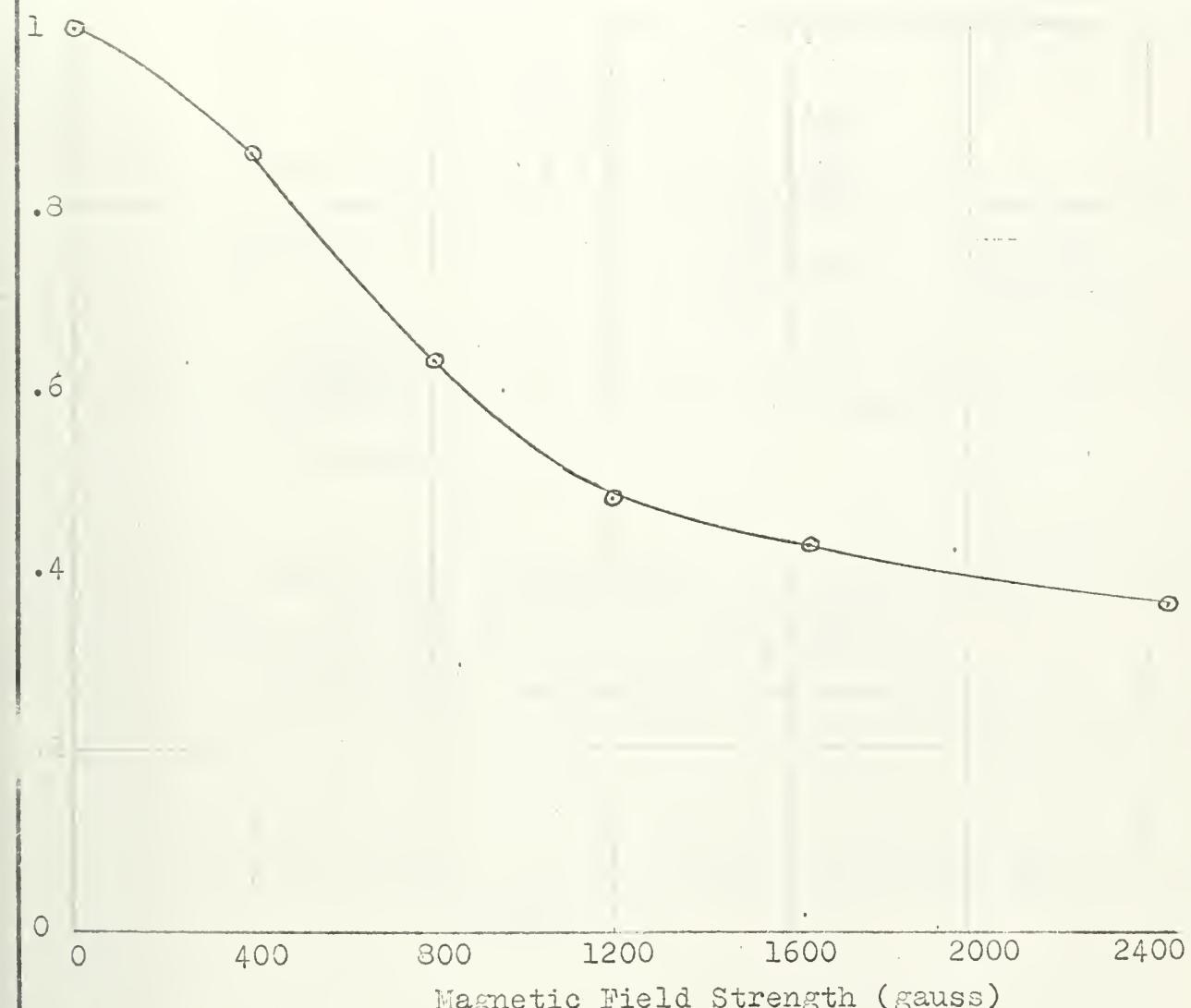
Signal Output Vs Magnetic Field Strength

Figure 13

35
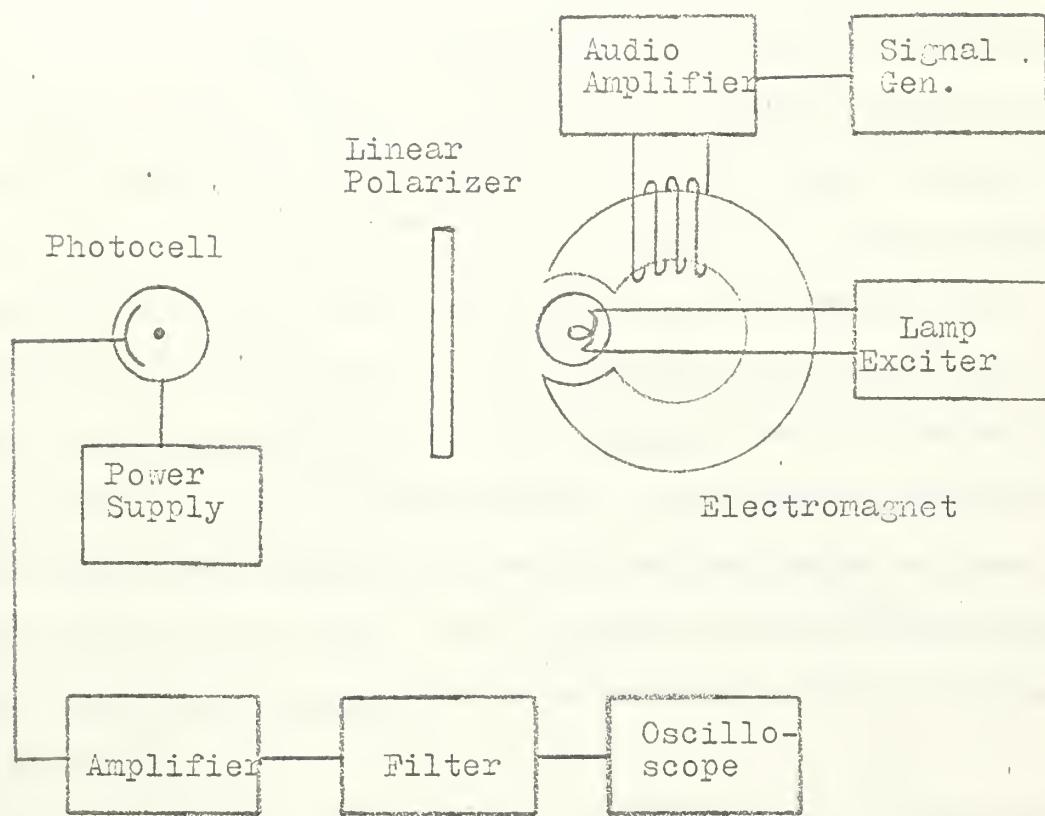
Block Diagram of Zeeman Modulation Experiment

Figure 14

IV. Conclusions

The modulation of the transmitting light utilizing the Zeeman effect and its reception and demodulation by a discharge photocell has demonstrated the feasibility of using helium resonance radiation in an infrared communications system. It was noted that during the Zeeman modulation experiment a signal to noise ratio of only 3 to 1 was obtained. Analysis of the oscilloscope traces show that the magnetic pickup accounted for approximately 90 to 95 percent of the noise present. This magnetic pickup was due to the proximity of the electromagnet to the detector cell and associated wiring. In a practical system, the transmitter would necessarily be remote from the receiver and this magnetic pickup would not exist. Had the magnetic pickup in the experimental setup been removed, signal to noise ratios of about 30 to 1 would have been observed.

From the curve of signal versus pressure, it is concluded that the optimum pressure in the discharge photocell would be in the range of 1100 to 1200 microns. Within its spectral range, the frequency response of the discharge photocell compares favorably with most of the available infrared photo-detectors.

Due to noise consideration, the detector-oscillator appears to be a better method of coupling the cell to the indicator than the resistor-capacitor method.

The presence of the buffer gas in the discharge photocell made the frequency response more uniform, but it so severely reduced the sensitivity of the photocell it is concluded that it would be preferable to avoid the use of a buffer gas, gain the higher sensitivity of the pure helium,

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and obtain the required frequency response uniformity by means of modern electronic equalization techniques.

The magnet used during the experiment was a relatively crude instrument. Much greater magnetic field strengths could be obtained for comparable currents with a more optimum design of the magnet. As the impedance of the magnet increases linearly with frequency, any source supplying power to the electromagnet would have to compensate for this effect.

The light source used during the experiment was the type used for spectroscopic studies and any communications system using this light source would be limited to short ranges due to lack of intensity. A high intensity helium light source must be developed before the system could be capable of operating over long distances.

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